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Landslide Hazard Zonation (LHZ) Mapping Using RS and GIS Techniques: A Case Study of Kumbur River Basin of Kodaikanal Taluk, Dindigul District, Tamilnadu, India

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Authors' contributions

This work was carried out in collaboration between all authors. Author RM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RB and RA managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Landslide is one of the disasters which lead to large-scale damage to properties and life. It frequently occurs in hilly regions like Himalaya, Western and Eastern Ghats. In Tamil Nadu, most of the landslides are often seen in Blue Mountains, Kodaikanal and Yercaud, occasionally in the other areas. Kodaikanal hills are facing two major problems viz. urbanization and environmental degradation. In this study, the landslide hazard zonation maps are prepared based on the causative factors of slope instability, namely thick soil accumulation, lithology, geological structure drainage density, slope morphometry, relative relief, land use and land cover and hydrogeological conditions in facet wise by using BIS code: IS 14496 (Part-2) – 1998. As per BIS classification method, Kumbur River Basin area, the distribution pattern of Landslide Hazard Zonation (LHZ)

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indicates that in the total 82 facets, 3 facets come under very high hazard category, 17 facets come under high hazard category, 40 facets are present in moderate hazards and remaining 25 facets come under range in low hazard.

Keywords: Landslide Hazard Zonation; Kumbur River Basin; RS and GIS; Kodaikanal hills.

1. INTRODUCTION

Kodaikanal hills have been the centre of urbanization in the past few decades. The frequent problems in Kodaikanal area are mainly road blockades due to slope failure along the roadside during rains leading to smaller and medium slide due to unplanned construction, drainage and agricultural activities. The construction activities in the form of resorts, hotels, houses, cottages and other structures have resulted in a large-scale deforestation. The tourist's inflow has increased alarmingly in the past few years, evidenced by a large number of new resorts in and around Kodaikanal municipality.

Landslides are one of the natural disasters which account for huge damage to properties in terms of direct and indirect risk [1]. The term "landslide" basically means a slow to rapid downward movement of instable rock and debris masses aided of gravity which can be categorized into various types on the basis of slope failure characteristics [2]. Increase in population and rapid urbanization has led to the expansion of construction activities in hilly terrain and has catapulted frequency of landslides to dramatic proportions in recent decades [3]. The present study areas, Kumbur River Basin of Kodaikanal Taluk are prone to landslides and were affected by frequent landslides in the past. In October 2011, heavy rain resulted in landslides at Kumbur River Basin, high range areas of Dindigul district bordering Tamilnadu State, caused massive loss to crop and property. Similarly, in October 2012, inclement weather condition brought heavy-rain at Mannavanur, Poondi, on various areas of Kodaikanal taluk. Damage on farmland and houses were reported. Traffic was disrupted on several arterial roads, including Mannavanur and Poondi-Kodaikanal highway road, as the water level rose drastically in Kumbur River [4,5] and [6].

The reliability of the hazard analysis depends on various factors and methods deployed [7] and [8]. Various methods of analysis have been proposed by many different authors [9,10,11] and [12]. Saranathan et al prepared landslide susceptibility zonation (LHZ) map for the upland catchment of river Kumbur Kodaikanal Taluk, Tamilnadu, India using GIS techniques by recognizing and mapping the paleo-slide locations and the associated terrain attributes [6]. The terrain parameters such as geomorphology, drainage density, soil type, soil thickness, land use, Normalized Difference Vegetation Index (NDVI), slope stability aspect, relative relief, slope length, profile curvature, plan curvature, flow path length and topographic wetness index were selected for this study [4] and [5]. Using GIS techniques and Weights of Evidence (WofE) model, the present research demonstrates the application of weighted overlay analysis method to produce the landslide hazard zone map for Kumbur River Basin [13] and [14].

2. METHODOLOGY

2.1 Study Area

Kodaikanal is situated in the southern tip of the upper Palani hills in the Western Ghats and a long history of hill resorts in Dindigul district, Tamil Nadu. Mannavanur, Poondi town is situated in the central part of the Study area. It has a total geographical area of about 104.7736 sq. km and extent from 10^{o} 07'00" N to 10^{o} 16' 00" N latitude and between 77^{o} 16' 00" E to 77^{o} 21' 00" E longitude. The sub-watershed is partly covered by 58F/7sw, 8nw, and 8sw of Survey of India Toposheets.

The base map incorporating main details and reference information was prepared from above said toposheets. Using land use, soil and rainfall data, runoff the potential of each facet is identified and it is a supplement to prepare landslide hazard zonation [15,16] and [17].

2.2 Geology and Structural Discontinuity

The study area is underlain of Archean age, Charnockite and Gneisses are being the major formation. A major portion of Study area largely covered by Charnockite rock and it is covered by about 90% of the taluk area. The remaining area comes under Hornblende Biotite gneiss. One of the gneissic bands is running along Mannavanur-Kumbur road and Kilavarai-Natampatti area and another small batch of the gneissic band is seen in Poondi area. Fig. 2 shows Geology and structure of the study area, derived from Geological Survey of India, Chennai and structure features extracted from aerial photographs, 1985 and satellite image IRS-1C, LISS III, March 2008, National Remote Sensing Centre, Hyderabad (with limited field check) [18] and [19].

The structural discontinuity in relation to the slope angle and direction has a greater influence on overall stability condition of the area [20]. The structural discontinuities were covered in 82 facets and they are furnished in Table 3 and these observed structural details are plotted on stereo-net (Fig. 3). As per the relationship of structural discontinuity with slope, the numerical ratings for each of the situations in either plainer or wedge mode evaluated and possible failure is obtained.

2.3 Rainfall

The precipitation occurs during from season viz. South-West monsoon from June to September, North-East monsoon across October to December, winter falls between January and February and summer showers from March to May. The period from May to November is the chief rainy season during which period about 70 to 80% of annual rainfall is received. The area gets rain from two monsoon seasons, the south-west monsoon and the north-east monsoon. The south-west monsoon starts in June and ends in September. The north-east monsoon season is from October to November. The highest rainfall was recorded at Mannavanur and the lowest recorded at Kilavarai. The average rainfall is around 102.6 mm per year.

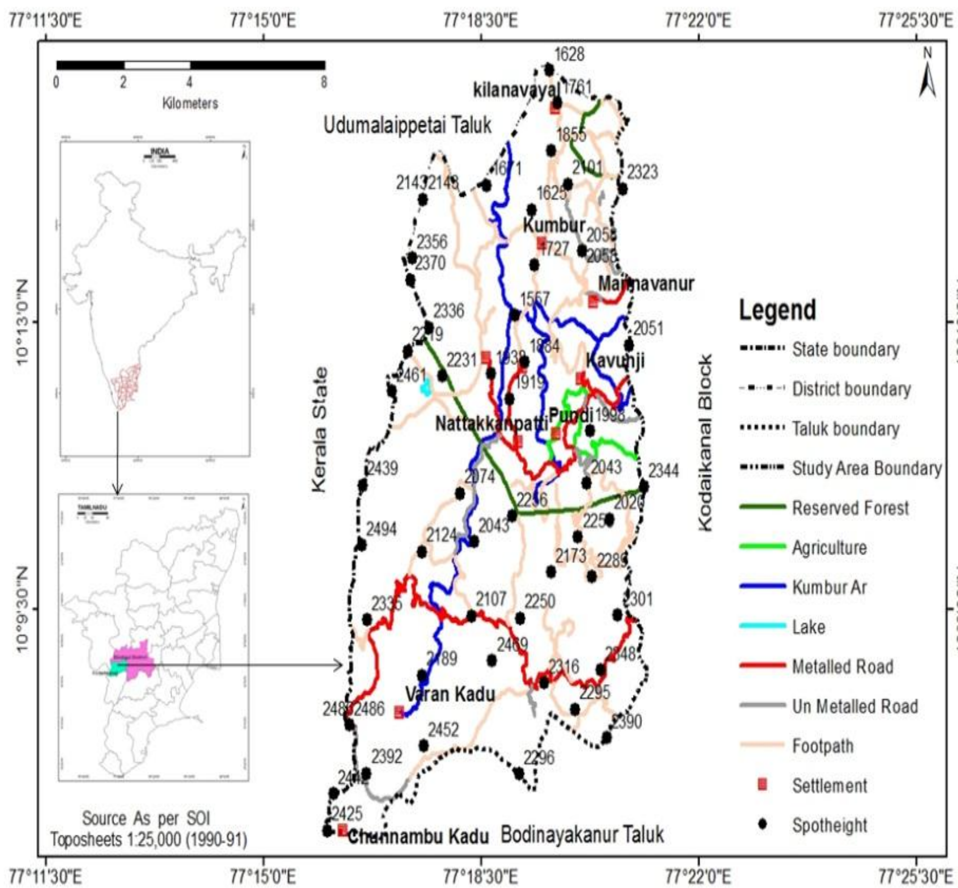

Fig. 1. Location Map of the study area

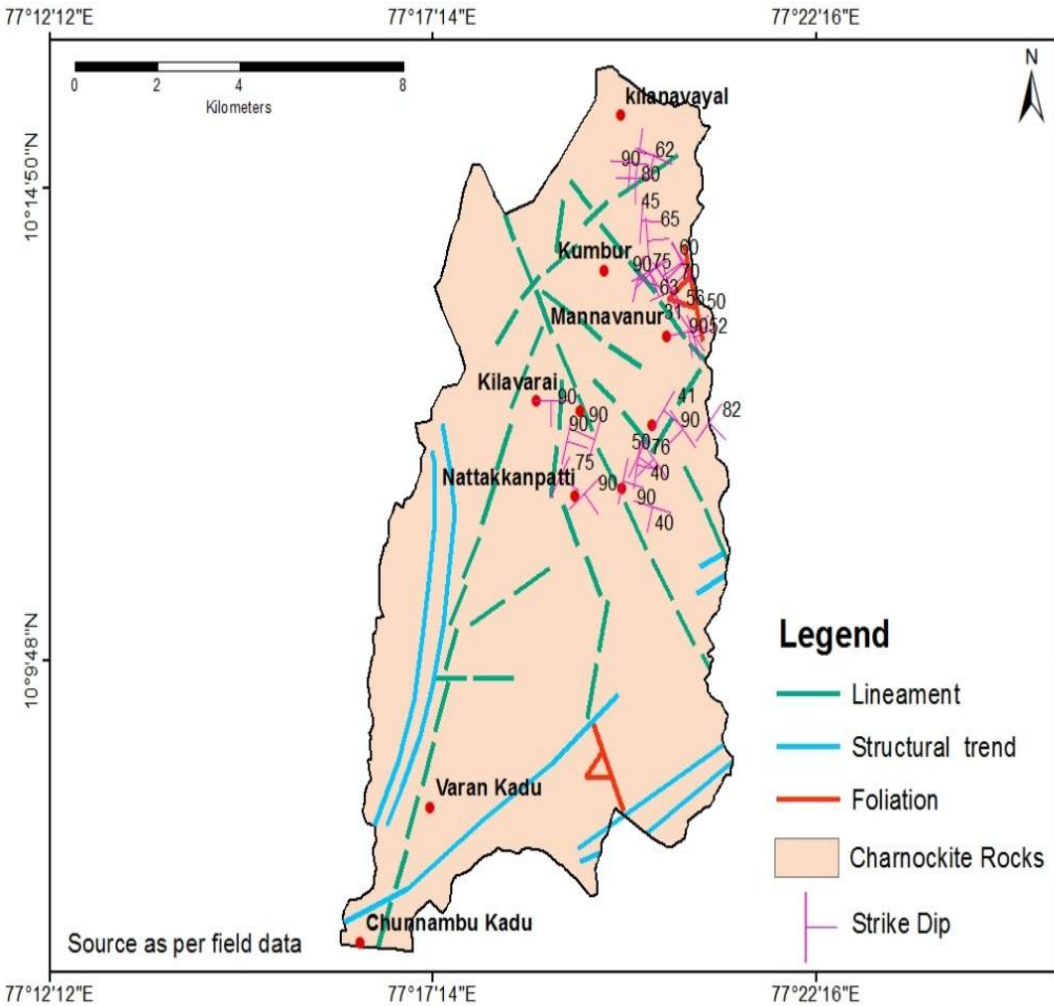

Fig. 2. Geology and Structure

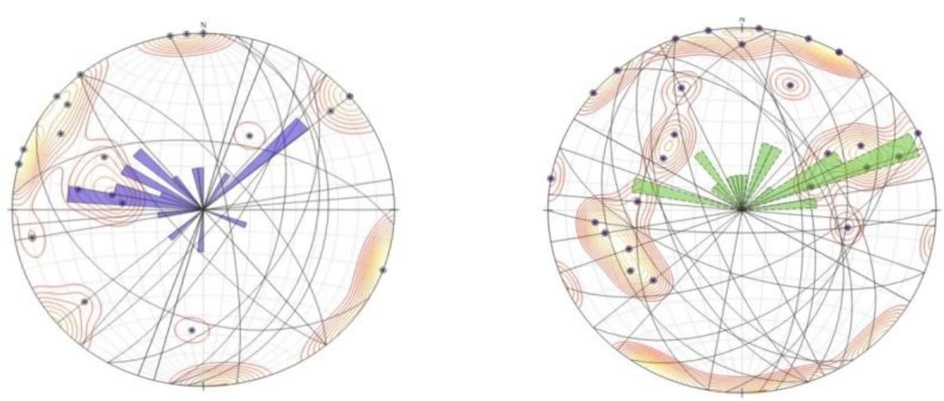

Fig. 3. Stereo Net

Table 1. List of structural discontinuities

Sl. No	Latitude – Longitude	Structural Details		Remarks
1.	10^o 11. 30 N - 77^o 20. 06 E	J1 Strike	N 105^o	Poondi
		Dip Direction	N 35^o W	
		Dip	40^o	
2.	10^o 11. 46 N - 77^o 19. 31 E	J1 Strike	N 50^o	Nattampatti Road Cut
		Dip Direction	N 20^o E	
		Dip Amount	90^o	
		J2 Strike	N 20^o	
		Dip Direction	N 60^{o}E	
		Dip Amount	90^o	
3.	10^o 12. 09 N - 77^o 19. 11 E	J1 Strike	N 15^o	Pollur Road cut
		Dip Direction	N 80^{o}E	
		Dip Amount	90^o	
		J2 Strike	N 80^o	
		Dip Direction	N20^{o}W	
		Dip Amount	90^o	
4.	10^o 12. 19 N - 77^o 19. 21 E	J1 Strike	N 30^o	Pollur agriculture
		Dip Direction	N 60^o W	
		Dip Amount	50^o	
5.	10^o 11. 68 N - 77^o 19. 02 E	J1 Strike	N 15^o	Kilavarai Road cut
		Dip Direction	N260^{o}W	
		Dip Amount	90^o	
		J2 Strike	N 5^o	
		Dip Direction	N250^{o}W	
		Dip Amount	35^o	
6.	10^o 12. 42 N - 77^o 18. 79 E	J1 Strike	N 10^o	Kilavarai Agriculture
		Dip Direction	N 260^o E	
		Dip Amount	40^o	
7.	10^o 11. 89 N - 77^o 20. 04 E	J1 Strike	S 200^o	Poondi Agriculture
		Dip Direction	N 100^o E	
		Dip Amount	90^o	
8.	10^o 11. 91 N - 77^o 20. 03 E	J1 Strike	N 30^o	Poondi Agriculture
		Dip Direction	N310^o W	
		Dip Amount	75^o	
9.	10^o 11. 84 N - 77^o 20. 02 E	J1 Strike	N 90^o	Poondi Agriculture
		Dip Direction	N 10^{o}E	
		Dip Amount	90^o	
		J2 Strike	N 140^o	
		Dip Direction	N 75^o E	
		Dip Amount	90^o	
10.	10^o 12. 39 N - 77^o 20. 36 E	J1 Strike	N 350^{o}E	Kavunchi
		Dip Direction	N 20^o W	
		Dip Amount	80^o	
11.	10^o 12. 16 N - 77^o 20. 40 E	J1 Strike	N 40^o	Kavunchi to Poondi Road cut
		Dip Direction	N 320^{oW}	
		Dip Amount	82^o	
12.	10^o 12. 31 N - 77^o 20. 38 E	J1 Strike	N 140^o	Kavunchi water falls
		Dip Direction	N 240^{o}W	
		Dip Amount	76^o	
13.	10^o 13. 16 N - 77^o 20. 61 E	J1 Strike	N 140^o	Mannavanur
		Dip Direction	N 55^{o}E	
		Dip Amount	90^o	
14.	10^o 13. 54 N - 77^o 20. 81 E	J1 Strike	N 320^o	Mannavanur Agriculture
		Dip Direction	N 60^o E	
		Dip Amount	70^o	

Sl. No	Latitude – Longitude	Structural Details		Remarks
15.	10^o 13. 29 N - 77^o 20. 79 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount J3 Strike Dip Direction Dip Amount	N 40^o N 325^o W 90^o N 120^o N 205^oW 90^o N 35^o N 310^oW 41^o	Mannavanur Road cut
16.	10^o 13. 39 N - 77^o 20. 75 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount	N 160^o N 60^oE 46^o N 150^o N 65^oE 60^o	Mannavanur Agriculture
17.	10^o 13. 86 N - 77^o 20. 47 E	J1 Strike Dip Direction Dip Amount	N 160^o S 240^oW 58^o	Mannavanur to Kizhanavayal Road cut
18.	10^o 13. 94 N - 77^o 20. 41 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount J3 Strike Dip Direction Dip Amount	N 10^o N 90^oE 90^o N 110^o N 15^oE 62^o N 95^o N 200^oW 90^o	Mannavanur to Kizhanavayal Road cut
19.	10^o 13. 94 N - 77^o 20. 40 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount	N 90^o N 190^oE 80^o N 70^o N 340^oW 90^o	Mannavanur to Kizhanavayal Road cut
20.	10^o 13. 97 N - 77^o 20. 39 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount	N 5^o N 280^oW 45^o N 355^o N 75^oE 65^o	Mannavanur to Kizhanavayal Road cut
21.	10^o 15. 18 N - 77^o 20. 06 E	J1 Strike Dip Direction Dip Amount J2 Strike Dip Direction Dip Amount J3 Strike Dip Direction Dip Amount	N 160^o N 85^oE 31^o N 50^o N 150^oE 90^o N 120^o N 40^oE 90^o	Mannavanur to Kizhanavayal Road cut
22.	10^o 15. 03 N - 77^o 20. 07 E	J1 Strike Dip Direction Dip Amount	N 110^o N 20^o E 90^o	Mannavanur to Kizhanavayal Road cut
23.	10^o 14. 79 N - 77^o 19. 89 E	J1 Strike Dip Direction Dip Amount	N 65^o N 165^o E 63^o	Mannavanur to Kizhanavayal Road cut Murugan Temple

Sl. No	Latitude – Longitude	Structural Details		Remarks
24.	10° 14. 47 N - 77° 20. 10 E	J1 Strike	N 40°	Mannavanur to Kizhanavayal Road cut
		Dip Direction	N 125°E	
		Dip Amount	90°	
		J2 Strike	N155°	
		Dip Direction	N 80° E	
		Dip Amount	90°	
25.	10° 14. 28 N - 77° 20. 18 E	J1 Strike	N 160°	Mannavanur to Kizhanavayal Road cut
		Dip Direction	N 80°E	
		Dip Amount	75°	
		J2 Strike	N 145°	
		Dip Direction	N 55°W	
		Dip Amount	45°	
		J3 Strike	N 50°	
		Dip Direction	N 330° W	
		Dip Amount	45°	
26.	10° 13. 66 N - 77° 20. 20 E	J1 Strike	N 80°	Mannavanur to Kumbur Road cut
		Dip Direction	N 345°W	
		Dip Amount	90°	
27.	10° 13. 67 N - 77° 20. 19 E	J1 Strike	N 340°	Mannavanur to Kumbur Road cut
		Dip Direction	N 80°E	
		Dip Amount	52°	
28.	10° 13. 80 N - 77° 20. 17 E	J1 Strike	N 320°	Mannavanur to Kumbur Road cut
		Dip Direction	N 50°E	
		Dip Amount	50°	
		J2 Strike	N 350°	
		Dip Direction	N 95°E	
		Dip Amount	61°	
29.	10° 13. 82 N - 77° 20. 12 E	J1 Strike	N 330°	Mannavanur to Kumbur Road cut Near Drainage
		Dip Direction	N 250°W	
		Dip Amount	56°	
		J2 Strike	N 330°	
		Dip Direction	N 50°E	
		Dip Amount	61°	
		J3 Strike	N 52°	
		Dip Direction	N 340°W	
		Dip Amount	90°	
30.	10° 13. 81 N - 77° 20. 05 E	J1 Strike	N 10°	Mannavanur to Kumbur Road cut Near Drainage
		Dip Direction	N 90°E	
		Dip Amount	56°	
		J2 Strike	N 85°	
		Dip Direction	N 165°E	
		Dip Amount	90°	
		J3 Strike	N 275°	
		Dip Direction	N 10°E	
		Dip Amount	58°	

**J1, J2 and J3 represents Joints at a particular location*

The different data used in the study area as follows,

i) Base map prepared from a topographical map of Survey of India at 1:25,000 scale.
ii) Geological map from Geological Survey of India, Chennai.
iii) Land use/land cover map derived from IRS -1C LISS III March 2008, Geocoded satellite imagery, National Remote Sensing Centre, Hyderabad.
iv) Field data involving observations of lithology, structure, slope morphometry, relative relief and hydrogeological conditions.
v) Software used ArcGIS 10.3, ERDAS Imagine 2015.

The methodology followed was based on the Bureau of Indian Standards 14496 (part 2) 1998. The Landslide Hazard Zonation of this area has been prepared using the maximum landslide hazard evaluation factor rating scheme (LHEF) and the total estimated hazard (TEHD). LHEF is a numerical system is based on the major inherent causative factors of slope instability such as lithology, structure, slope morphometry, relative relief, land use/land cover and hydrogeological conditions. A detailed LHEF rating scheme showing ratings for different types of subcategories for individual causative factors [15] shown in Tables 1 and 2. The total estimated hazard indicates the net probability of instability calculated facet wise. The TEHD of an individual facet was obtained by adding the ratings of the individual causative factors obtained from LHEF rating scheme. On the basis of TEHD, five categories - very low hazard zone (< 3.5), low hazard zone (3.5–5.0), moderate hazard zone (5.1–6.0), high hazard zone (6.1–7.5) and very high hazard zone (> 7.5) were classified [15,16] and [17].

3. RESULTS AND DISCUSSION

A detailed evaluation of landslide hazard evaluation factor rating scheme (Tables 1 and 2) showing numerical weightages of sub-watershed of all the causative factors has been made for each facet identified. Based on the Landslide Hazard Evaluation Factor rating for individual facets, Total Estimated Hazard (TEHD) was estimated for different facets by adding the rating values for individual facets. Facet wise distribution of the TEHD values in the area facilitates classification of the terrain into different hazard zones for Kumbur basin sub-watershed [20]. As per the BIS classification method, five different types of landslide hazard zonation are mentioned. Fig. 8 shows Landslide Hazard Zonation of the study area. The distribution pattern of Landslide Hazard Zonation indicates that 3 facets are in very high hazard, 17 facets are in high hazard 40 are in moderate hazards, 10 facets go in low hazard range and remaining 12 facets go in very low hazard range.

The correction factor for weathering

(i) Highly weathered – rock discoloured, joint open with the weathered product, rock fabric alter to a large extent – correction factor C1
(ii) Moderately weathered – rock discoloured with fresh rock patches weathering more around joint planes but rock intact in nature correction factor C2
(iii) Slightly weathered – rock slightly along joint planes, which may be moderately tight to open intact rock-correction factor C3. The rock correction for weathering to be multiplied with the fresh rock rating.

For rock type-I, C1=4, C2=3, and C3=2

For rock type-II, C1=1.5, C2=1.25, and C3=1.

3.1 Facet Map

The landslide hazard zonation map of the study area is prepared on a facet map, which in turn is derived from the topographical map. The facet map is prepared by demarcating slope facets on the Survey of India Toposheets No. 58F/7SE, 58F/8NE, 58F/11SW and 58F/12NW of 1:25,000 scale by dividing the topographical sheet into smaller facet. The slope facets are generally delineated by ridge break in slope, stream, spurs etc. Overall 82 facets are identified in this area shown in Fig. 4.

3.2 Slope Morphometry

The slope morphometry map defines various slope categories of the study area and is prepared out of USGS/NASA SRTM image of 90 m resolution (2007).

Table 2. Maximum LHEF Causative factor ratings

S. no	Causative factor	Maximum LHEF Rating
1.	Lithology	2
2.	Structure	2
3.	Slope Morphometry	2
4.	Relative relief	1
5.	Land Use and Land Cover	2
6.	Hydrological conditions	1

(Source: BIS code no: (IS: 14496 (part-2); 1998)

Table 3. Landslide Hazard Evaluation Factor (LHEF) Rating Scheme (IS: 14496 (part-2); 1998)

Contributory factor				Rating
I. Lithology	**Type - I**			
Rock type	Quartzite and limestone			0.2
	Granite and gabbro			0.3
	Gneiss			0.4
	Type - II			
	Well cemented sedimentary rocks dominantly			1
	Sandstone with minor beds of claystone			
	Poorly cemented sedimentary rocks dominantly			1.3
	Sandstone with minor clay-beds			
	Type - III			
	Slate and phyllite			1.2
	Schist			1.3
	Shale inter-bedded with clayey and non-clayey rocks			1.8
	Highly weathered shale, phyllite and schist			2
	Older well cemented fluvial fill material			0.8
	Clayey soil with naturally form surfaces			1
	Sandy soil with naturally form surface (alluvial)			1.4
Soil type	Debris comprising mostly rock pieces mixed with Clayey/sandy soil (colluvial)			
	older well compacted			1.2
	Younger loose material			2
II. Structure	(i) Relationship of parallelism	I	> 30º	0.20
	Between the slope	II	21º-30º	0.25
	Discontinuity	III	11º-20º	0.30
	Planar	IV	6º-10º	0.40
	Wedge	V	< 5º	0.50
	(ii) Relationship of dip	I	> 10º	0.3
	Discontinuity and inclination	II	0º-10º	0.5
	Slope	III	0º	0.7
	Planar	IV	0º-(-)10º	0.8
	Wedge	V	>(-)10º	1
	(iii) Dip of discontinuity	I		0.20
		II		0.25
		III		0.30
		IV		0.40
		V		0.50
	Depth of Soil cover		< 5 m	0.65
			6-10 m	0.85
			11-15 m	1.30
			16-20 m	2.00
			> 20 m	1.20
III. Slope morphometry				
(i) Escarpment/cliff			> 45º	2.0
(ii) Steep slope			36º-45º	1.7
(iii) Moderately steep slope			26º-35º	1.2
(iv) Gentle slope			16º-25º	0.8
(v) Very gentle slope			< 15º	0.5
IV. Relative Relief				
(i) Low			<100m	0.3
(ii) Medium			101-300m	0.6
(iii) High			>300m	1.0

Contributory factor	Rating
V. Land use and land cover	
(i) Agricultural land/populated flat land	0.6
(ii) Thickly vegetated forest area	0.8
(iii) Moderately vegetated area	1.2
(iv) Sparsely vegetated area with lesser ground cover	1.5
(v) Barren land	2
VI. Hydrogeological conditions	
(i) Flowing	1
(ii) Dripping	0.8
(iii) Wet	0.5
(iv) Damp	0.2
(v) Dry	0

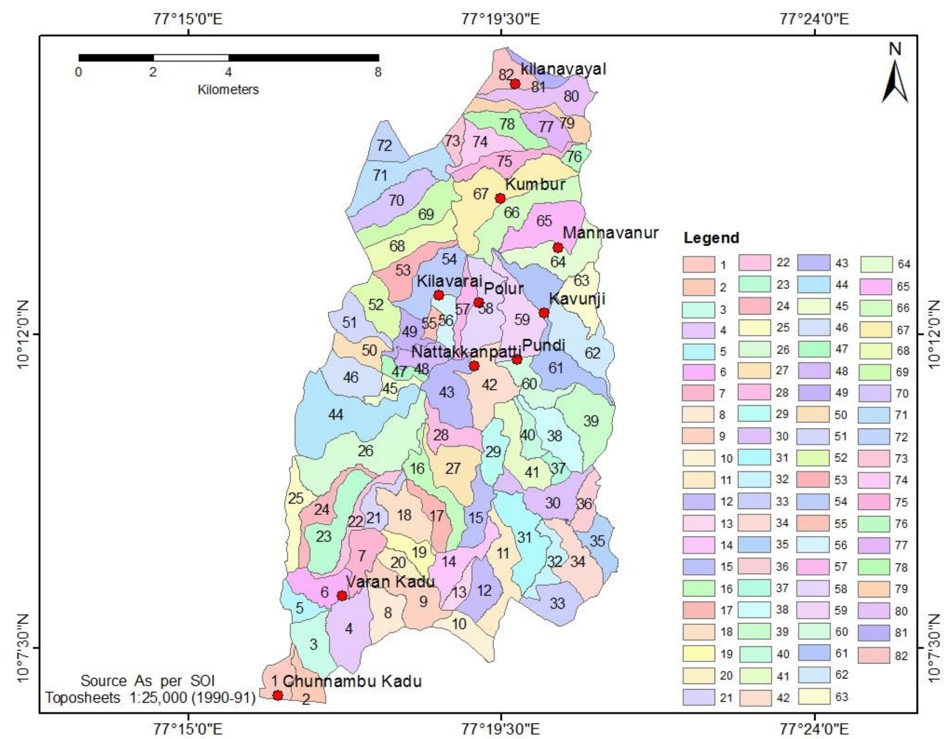

Fig. 4. Slope Facet Map of the Study Area

The distribution pattern of slopes in this area varies from very gentle slope to escarpment, ranges between 0.5 and 2.0 respectively. The sub-watershed cover about 50 facets are in ranges on 35° – 45° inclination, 20 facets in 25° – 35° inclination and 12 facets in 15° –25° ranges and remaining have slopes more than 45° inclination shown in Fig. 5.

3.3 Relative Relief

The relative relief value of each face is calculated by using SOI Toposheets and LHEF rating given to each facet.

The area generally has very high relative relief of about 260 m and high relative relief of about 170 m and moderate relative relief of about 120 m and followed by the medium of about 92 m and remaining 66 m is low relative relief shown in Fig. 6.

3.4 Land Use and Land Cover

Land use and land cover map where prepared by using NRSA classification and interpreted from IRS 1C and LISS III imagery. Land use and land cover map are the indirect indications of the stability of the hill slopes. In the Kumbur basin

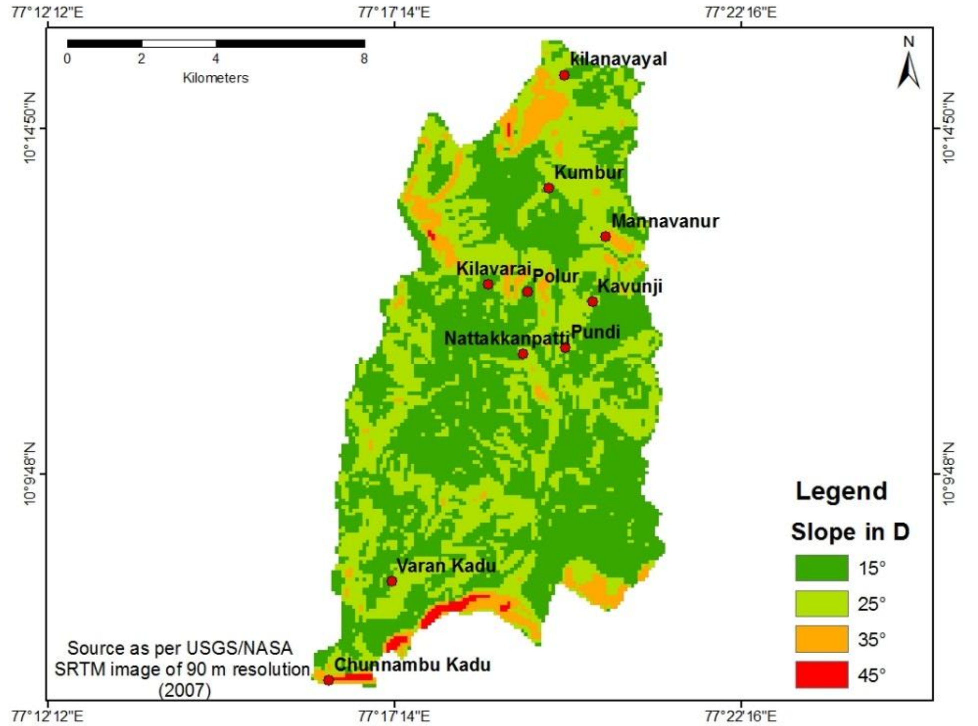

Fig. 5. Slope map of the study area

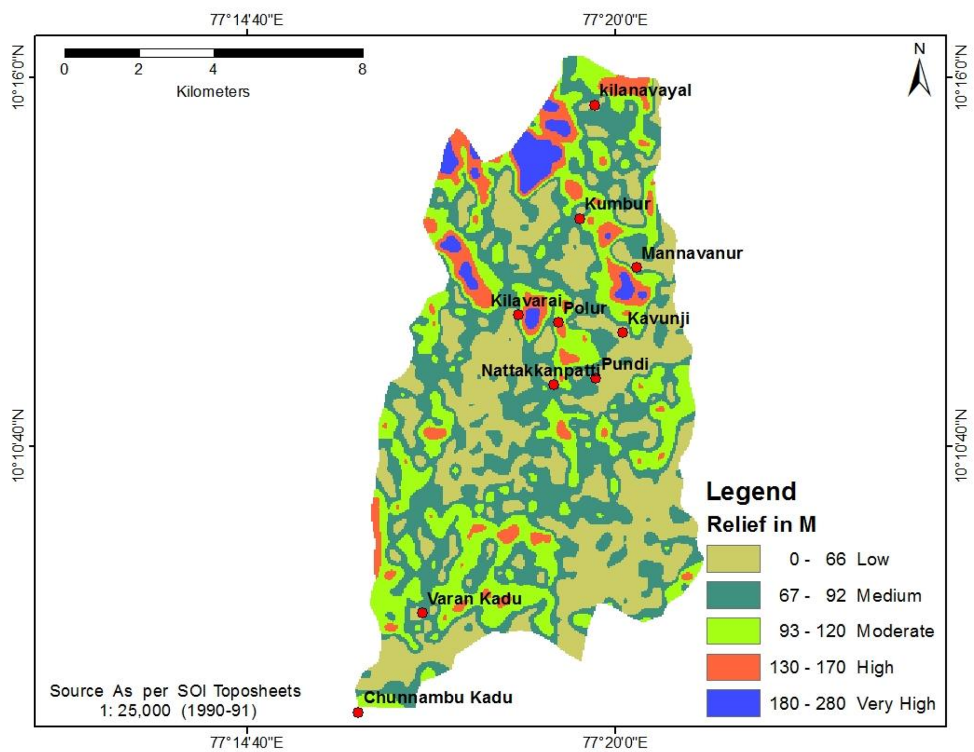

Fig. 6. Relative relief map of the study area

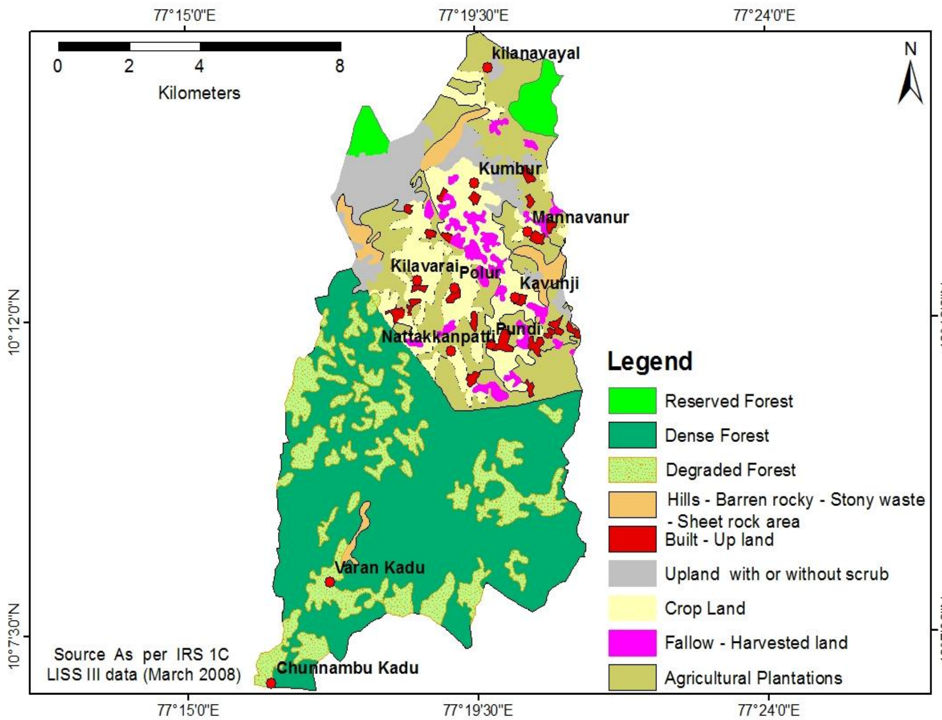

Fig. 7. Land use map of the study area

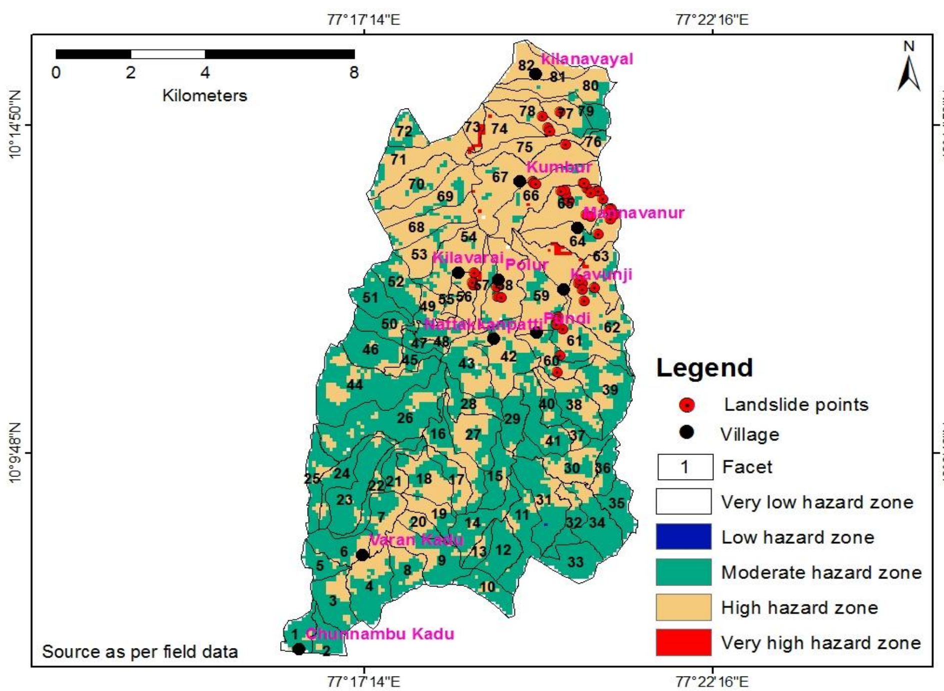

Fig. 8. Landslide Hazard Zonation map of the study area

sub-watershed, 12 different types of land use classes were identified such as Settlement, Crop Land, Fallow Land, Plantation, Dense Forest, Degraded Forest, Forest Blank, Scrub Land, Barren Rocky, and River and reclassified into as per LHEF ratings. While agriculture and plantation are the dominant land uses under the classification present in this area. About 72% of the total area is occupied by agricultural activities. Though scrubland is occupied around 12.35% of the area, most of the settlement is noticed in the southern part of the sub-watershed. The Reserve Forest lands are situated in the southwest and southeast parts of the study are shown in Fig. 7.

3.5 Hydro-geology

After monsoonal season, Hydrogeological conditions congregated from the field, for the reason that rainfall is an important triggering factor of the vulnerable slides in hilly region. The hydro-geological conditions of the sub-watershed show that eastern, central and southwestern parts of the facets are generally damp in conditions. Most of these areas are coming under agricultural activities; about 50 facets are shown in this condition. Sub-watershed shows that North and Northeastern portions, Kizhanavayal area, Kumbur area are normally wet in condition. It is clearly shown that in these areas few springs are present. About 27 facets are coming under this condition. Remaining 5 facets are in dripping condition.

4. CONCLUSION

LHZ mapping is a pragmatic approach which takes into accounts both inherent and external factors for slope instability. Stable zones like low hazard considered safe for civil constructions. Hill slopes falling in moderate hazard classes are also safe for construction practice, but may contain local instability conditions, which should be suitably accounted during constructions. For slopes falling in high hazard classes, it is always advisable to avoid constructions. For land developers eager to constructs on high hazard classes' areas are subject for Detailed Geotechnical and Engineering studies.

The results of the present study can help citizens, planners and engineers to reduce losses caused by existing and future landslides by means of prevention and mitigation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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